A USER VIEW OF THE EURECA GROUND SEGMENT

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ABSTRACT

EURECA, the EUropean REtrievable CArrier was launched on July 31st 1992. It is the largest ESA spacecraft ever launched, and the first one to be launched and retrieved by the NASA Space Shuttle.

The many new aspects of this mission affected the operations concept and the ground segment design in all important areas: an off-line concept for mission control has been applied, based on automatic commanding and post-contact telemetry analysis; mission planning is the centre of all routine operations activities using dedicated tools and operational techniques; high precision orbit determination and daily update of related telecommands for spacecraft control are needed to cope with the requirements coming from the low altitude orbit and the spacecraft attitude control design.

The paper describes the lessons learned during the first months of utilisation of the EURECA ground segment from the point of view of the flight control team.

Key Words: Mission control, operations, ground segment

1. INTRODUCTION

EURECA, the first European spacecraft designed to be retrieved and re-used for subsequent flights, was launched on July 31st 1992 on the NASA Space Shuttle Atlantis. After deployment it was manoeuvred to an operational circular orbit at 508 Km altitude, where it will carry out scientific operations for its fifteen payload instruments, mainly in the field of microgravity research and space science. After a planned mission of nine months the spacecraft will be transferred to a retrieval orbit, where it will rendez-vous with a new Space Shuttle, which will retrieve it and bring it back to Earth.

The EURECA ground segment was designed around the main mission characteristics of reduced visibility time and high level of spacecraft autonomy, large number of different possible payload operational configurations and packet telemetry and telecommand concepts. It consists of two ground stations in Maspalomas and Kourou, which provide about eight contact periods of 5 to 10 minutes each every day, spaced by one orbit which lasts about 90 minutes (a long non-coverage period of about 9 hours occurs daily between two sequences of station passes); and a control centre located in Darmstadt, which can also make use of a third station in Perth as a back-up.

For the periods when EURECA was attached or in proximity of the Space Shuttle contact with the spacecraft was established via the NASCOM network, the NASA TDRS system and the Orbiter itself used as a data relay station. In those periods, which include the first two days and the last few days of the mission, the contact with the spacecraft is practically continuous, and a completely separate telemetry and telecommand interface, as well as a different way of operation had to be defined.

This paper does not describe the EURECA ground segment and control system, but rather the direct operational experience accumulated with the different parts of it and makes suggestions for possible future improvements.

2. MISSION CONTROL SOFTWARE

2.1 Database Editors

The EURECA operational database was built manually using the manufacturer's spacecraft database developed for the system level testing activities, complemented by information collected in a large number of design documents. More than 8000 telemetry parameters, 2500 telecommands and 4800 report messages had to be defined, an enormous task in terms of time and manpower both for creation and later maintenance of the files.

The editors used for this task within the EURECA Dedicated Control System (EDCS) were also constraining this work, not providing the necessary level of flexibility, in particular when large changes to the source database had to be introduced. The solution of automatically importing into the operational database the industry developed spacecraft database would have helped in the traditional areas like housekeeping telemetry definition; the flexibility given by the EURECA packetised telemetry and telecommand concept would have been however significantly constrained if the entire database definition had been left to the industry.

A mixed solution of general database information imported directly and later processed using editors which are more change- oriented rather than input-oriented would probably satisfy all the needs of such a complex database generation task.

2.2 User Interfaces

The user interface for most of the tasks provided by EDCS to the EURECA flight control team is provided on workstations with very limited graphic capabilities, low speed of interaction with the central computer, and in general reduced flexibility in the use of the three available displays.

For a complex mission like EURECA the standard spacecraft monitoring and commanding tasks controlled via the workstations require more display space for command building and displaying of the different types of telemetry; in addition several tasks related to ground data management and interface with the ground stations have also to be carried out by the spacecraft controller using the workstation. This resulted in an increased need of display availability, which can hardly be satisfied by the arrangement provided by the workstations. The limited graphic capabilities impact in particular the off-line data analysis carried out daily by the flight control engineers.

The combination of workstation and user interface limitations also practically prevented the creation of a database of mimic displays, normally very effective in summarising information and thus allowing savings in space and time.

Interactive generation of telemetry displays is provided for graphic and alphanumeric scrolling displays. This was extensively used during system and spacecraft tests, and it is still found very useful for quick-look analysis of unexpected spacecraft behaviour during flight. This type of features should be extended to all types of telemetry displays, from alphanumeric to mimic; the system should also allow a direct consolidation of the changes performed interactively at the workstation into the operational database without going through the editors.

A transition to modern, window-oriented workstations is taking place at ESOC. The use of the currently existing application software via the new workstations has already proven to sensibly improve the system effectiveness. A combination of task-dedicated displays and windowed displays is considered to be the optimum solution.

2.3 Telemetry Processing

The telemetry processing system makes full use of a new system software designed to handle packetised telemetry. Different tasks had to be designed to cope with the NASCOM interface for the mission phases when telemetry is routed via the Space Shuttle through the NASA communications network, and the ground station interface for the other phases of the mission.

Standard telemetry processing features are provided, like limit checking, validity and derived parameters calculation for the housekeeping telemetry packets. Other types of packets are handled according to the type in different ways.

The problems experienced with the telemetry processing system in this first part of the mission are all related to the way the system reacts to corrupted data received from the spacecraft. The large number of independent processors on-board EURECA increases the likelihood of unexpected behaviours which result in corruption of the format or contents of the TM packets produced. Very strange anomalous behaviours have been observed in some of the payload processors, like position shifts of packet time field or overflow in the packet counter, which caused serious problems to the ground software, ranging from continuous alarm generation to crashes of the telemetry processing tasks. In most of the cases ad-hoc software patches have become necessary on-ground to cope with the new or sporadic anomalous situation.

The design of a telemetry processing system has to be based on some assumptions on the structure of the data to be processed, and is therefore particularly vulnerable when the perverse behaviour of an on-board processor corrupts the data in a specific and unexpected way. For the same reason, however, the system should be flexible enough to allow a rapid configuration of the telemetry processing software in order to adapt it to the new situation in case of an on-board failure. The system should for example allow the user to disable specific checks on selected packets, to modify the time calibration and filing rules for specific packets, without the need of software modifications.

2.4 Telecommands Handling

Three parallel command queues are provided for EURECA commanding during a ground station pass: the manual commanding queue, which allows real-time commanding with direct control on single telecommands or timed sequences; the pass schedule queue, which can be started in the background and executes a series of pre-configured commands at specified times relative to the start of the queue; the maintenance queue, which allows uplink of all the previously prepared time-tagged commands to be stored on-board for later execution. This arrangement allows the spacecraft controller to concentrate on the manual commands, leaving the control of the background automatic queues to the system; he is in control of the start and stop of the command activity via the background queues.

Very useful has proven to be the capability given to the user to create and store manual stacks of commands, which, together with the command files editors for pass schedules and master schedules provide the required flexibility to operate EURECA in the routine off-line way, but also to efficiently react in a short time to unexpected real-time commanding needs.

When problems in the command link are experienced, however, the normally very smooth commanding becomes extremely difficult to handle. In particular a better visibility of the commanding status for the different queues would be needed, including a direct presentation of spacecraft and ground station messages to establish the command status. Handling of uplink failures could also be improved by automating analysis tasks which are currently carried out manually whenever failures or interruptions occur during the uplink of automatic queues.

2.5 Automatic Command Verifier

One of the most useful and widely used software tasks in the EURECA control system is the automatic command verifier. The complexity of telecommand routing on-board EURECA and the variety of responses the spacecraft can generate which can be used to derive the success in telecommand réception and execution is handled by a single task. Based on user-defined rules contained in the definition of each telecommand in the operational database the command verifier task accesses all telemetry streams and summarises the telecommand verification result as one of 23 different states, ranging from complete success to complete failure; the resulting status is recorded in a telecommand history file.

The telecommand history of the previous 24 hours is analysed daily by an engineer, who concentrates his investigation only on those few commands which were not completely successful. Manually scanning through one day of telecommands - typically for EURECA routine operations this means about 800 telecommands -takes only a few minutes if all telecommands are successful. On the contrary, the investigation of the reasons for the failure of only a few telecommands can take a significant amount of time.

Possible improvements to help speeding up the trouble-shooting activities related to a failed telecommand could be in the area of automatic selection of telemetry information which is relevant to a selected telecommand; also an extension of the verification task to allow it to follow in telemetry the entire process initiated by a telecommand, and not only the successful start of the process, is under investigation. This is particularly feasible on a spacecraft like EURECA, where the high level of on-board automation results in long duration automatic processes, lasting even several days without intervention from ground; the process controllers produce periodic or event-driven messages in telemetry which give an indication of the progress of the activity.

2.6 Event Messages Handling

All payload instruments and most of the spacecraft subsystems on EURECA generate special telemetry packets, called event packets, which report asynchronously the success of a telecommand, the start, end or progress of an automatic process, hardware failures or any other unexpected event detected on-board. These packets are used in the telecommand verification process, but can also be displayed on a scrolling display which shows for each packet a fixed, user-defined text message for each packet. Many of these packets also contain housekeeping-like parameters: a typical example is a snapshot of the entire housekeeping telemetry of a payload instrument, generated by the instrument processor only at the time of a relevant event. This approach, adopted by several EURECA instruments, makes the best use of the packet telemetry concept, generating telemetry information only when it is necessary, thus avoiding high frequency housekeeping telemetry sampling and saving space in the downlink. Parameters contained in the event messages can be displayed as part of the text message attached to the packet and calibration or text interpretation can be applied to them in the same way as for normal housekeeping parameters.

However event packets parameters are still treated separately from the standard housekeeping parameters, and therefore not integrated in the rest of the telemetry processing, like limit checking, validity and derived parameters calculation. As there is in principle no difference from the on-board processor's point of view between housekeeping parameters transmitted in an event telemetry packet or in a standard housekeeping packet, this limitation of the EURECA telemetry processing system is arbitrary and causes some difficulties, in particular for those payload instruments which base their telemetry generation on the above described event-driven concept.

For future autonomous spacecraft event-driven reporting will most likely become more and more common; a full integration of event packet parameters in the telemetry processing chain will therefore be mandatory.

With its limitations the event messages display task remains nevertheless one of the most extensively used tools for monitoring of the on-going EURECA activities.

2.7 Flight Dynamics Interface

The role of flight dynamics software in routine mission control of EURECA is very important: the low altitude orbit requires daily updating of orbit determination and predictions; on-board attitude control and ground mission planning software also require frequent updates of orbit information, to keep attitude and planning accuracy within the specified requirements. In the first weeks of the mission a dedicated flight dynamics team was in charge of generating the necessary orbit and attitude related products using software tools running on a dedicated computer. With the progress of the mission and the start of the routine operations phase the flight dynamics team, which includes an independent quality control group in charge of verification of the generated products, has been gradually reduced with the target of leaving the routine flight dynamics tasks to a set of automatic routines which are started daily by a scheduler task. These routines perform all required tasks from collection of tracking data received from the ground stations and orbit determination to orbit prediction and related products generation, including orbit model telecommands to be transferred to the front-end computer for uplink to the spacecraft.

A weak point in this scheme is that telecommands are automatically generated which cannot be easily checked by the flight controllers in charge of uplinking them to the spacecraft. Any problem in the automatic generation software, which can also be caused by corrupted input data, is not detected any more by the quality control check carried out in the first part of the mission. The only protection the current system provides is limit-checking on telecommand parameters. This is however only effective on a limited number of parameters and by no means represents a complete check.

Some simple independent software checking is being implemented to trap any major problem with the automatically generated telecommands. A more consistent software, possibly based on the same routines which were developed and used by the quality control team during the early phases of the mission, should be implemented for future missions and integrated in a more comprehensive telecommand generation software.

3. SCIENCE OPERATIONS

3.1 Mission Planning

One area where the existing workstation interface had to be abandoned years ago is the mission planning task. This tool runs on an independent VAX workstation where the graphical and windowing capabilities are used in producing an effective user-interface.

On the other hand the mission planning is probably the area of the mission control software which is experiencing the most significant problems. The tool accepts scheduling inputs based on orbital constraints and, using a pre-defined database, it produces a resource consumption profile for all spacecraft resources available to the payload (eg. power, data storage, cooling capacity) by adding up the contributions from the single scheduled operations. If the total resource consumption goes above a pre-defined threshold the mission planning tool warns the user that a 'clash' is detected, allowing him to modify the payload operations schedule to solve the problem.

Experience has shown, however, that the type of operational constraints to be applied to payload operations scheduling are more complicated than simple relations to orbital events. Payload operations are often constrained by relations between activities to be executed on the same or on different payload instruments, ground activities, specific requirements by the investigators. This type of constraints is not handled by the mission planning software, and a combination of manual scheduling and user-developed software had to be adopted to simplify the actual planning tasks. An additional tool would be required to allow the planner to specify and modify rules to be used by the mission planning task to schedule the required payload operations. This tool should be flexible enough to allow specification of rules which are normally thought of or required by the investigators or by new developments in the spacecraft situation only later in the mission plan preparation and often even during the actual mission.

Resource consumption checking and clash detection handling turned out to be less critical than expected in the actual planning exercise: planners very soon acquire enough experience on possible payload configurations which allows them to manually produce feasible payload operations timelines. A lot of development effort was therefore put into a less important part of the software task.

Another problem experienced with the available tool is the little visibility the planner has on the already scheduled operations. This is in particular important when changes have to be implemented in already scheduled operations due to resource availability problems, new failures or new requests from the investigators. An analysis tool which allows to identify at any point of the scheduled timeline what payload operation is contributing to the overall payload configuration would be a significant improvement required for this task.

3.2 Data Disposition System

The science data generated by the payload are distributed to the users via electronic means: all consolidated spacecraft data are accessible from the users via a separate computer, which is linked to the operational machine and to the external world via different communications protocols for security reasons. A catalogue of available data can be requested via electronic mail by the user, who can then specify the appropriate request for data from his own instrument. Available to the user are also all spacecraft housekeeping data and other ancillary information files like future orbit events, attitude history or telecommand history.

The user can also specify, via the same electronic interface, requests for special operations to be conducted on his instrument, or changes to the pre-mission defined operations plan. This type of request, called TC Request, forms the input, together with the baseline payload operations plan, to the daily mission planning exercise.

Unfortunately the loop with the user is not closed electronically: TC requests cannot be input directly in the telecommand scheduling process but the related telecommands have to be manually generated by a mission planning engineer. A more automatic handling of TC requests was not possible due to the large number of payload instruments and different types of operation requests, together with the limited time and budget available for the development of this system.

A first necessary improvement of the interface with external users would be to allow the mission planner to include electronically the approved TC requests in the telecommand generation process. Automatic checking and approval of TC requests, allowing each user to remotely control his own instrument independently of the other spacecraft operations is the target, still far away from the EURECA approach, but at least visible in the distance.

4. GROUND STATIONS - CONTROL CENTRE INTERFACE

4.1 Telemetry Interface

Real time and on-board recorded telemetry is received and stored at the ground station by a telemetry frame pre-processor; During a telemetry dump the data rate reaches 256 Kbps and due to the lower capacity of the station to control centre link only a subset of the received data can be transferred in real-time. The control centre can pre-program the station unit to transmit any selection of telemetry packets or all real-time or recorded telemetry frames as received from the spacecraft.

During the pass only real-time telemetry is normally transferred directly to the EDCS, whilst the telemetry which is dumped from the on-board memory during the pass is transferred in the non-coverage period between two passes.

Whilst the nominal data transfer is adequately handled by EDCS, the problems start in case of interruptions during the data dump from the spacecraft or during the data transfer from the station.

If the problem was on the ground link the system allows the user to initiate a new transfer; unfortunately in this case a re-transfer of the entire selected data set is performed, and not simply of the data lost on the link. Due to the long duration of the transfer of all data dumped during the pass this becomes a very inefficient and time-consuming operation.

If the spacecraft-station link is interrupted during a telemetry dump the problem is more serious and difficult to detect and to recover. The system allows in fact detection and later filling of gaps created in the telemetry history files by any link interruption; however the tools available for this task are very complicated to use and require long manual investigations and calculations to determine where and when the problem occurred and what data have to be re-transferred. In many cases this time is of the same order of the wraparound time of the on-board memory, making the data recovery physically impossible.

A more efficient and user-friendly tool would be required to allow immediate detection of the gap, identification of whether the data were lost on the space-to-ground link or between the station and the control centre, and indicate what the recovery action should be. The necessary information is available on ground to completely automate the task, leaving to the operator only the decision whether to initiate the recovery process or not.

4.2 Telecommand Interface

Experience during the mission with the telecommand interface between EDCS and the ground station has been very positive, with hardly any problem occurred in more than three months and more than 80000 telecommands uplinked to the spacecraft.

Problems occurred in the development phase, due to the late decision to close the telecommand block protocol loop with the spacecraft at the control centre, and not, as initially foreseen, at the ground station. This increased dramatically the complication of the command uplinker software, which has to cope for every telecommand with a number of messages coming from different units at the station in addition to the telemetry messages from the spacecraft.

Testing this software in a realistic environment became absolutely necessary due to the importance of the timing aspects of the problem and this forced extension of precious testing time with the spacecraft flight model connected to a ground station interface.

For the NASA interface a complete realistic test was not possible, leaving the fine tuning of several configuration parameters to the actual flight experience.

Fortunately no correction to the uplinker software became necessary during the mission. It is however advisable, in order to simplify significantly the command interface software at the control centre, to close as much as possible of the space to ground loop at the ground station.

4.3 Tracking Interface

The interface with the ground station which deals with tracking data collection from and antenna pointing information transmission to the station was given a low priority in the software development phase, resulting in a relatively simple implementation.

EURECA tracking data are collected at the station by a unit called MPTS, which is remotely programmed for operation and data transfer from the control centre. The only problems experienced are also in this case in the area of the user interface, which gives little visibility to the spacecraft controller of the status of the unit and in particular of the contents and status of the programmed queues.

Antenna pointing information is generated by the flight dynamics automatic software, and transferred to the ground station by the network operators on a daily basis. In this case too, the operator in charge of the transfer has no visibility of the contents of the files he is transferring, and only when the data reach the station any problem that may have occurred becomes available. A recurrent problem in the first part of the mission was in fact that antenna pointing data were not reaching the station in time, or the station would request new data which were not yet available.

This type of visibility problems are usually worked around by experience and procedures improvement in the first months of the mission. However, a more elegant interface which links directly the flight dynamics generation software to the ground station computer and performs the data generation or transfer automatically or on request would be a significant improvement in this area.

5. CONCLUSIONS

The EURECA ground segment has to date successfully supported this challenging mission for almost half of its nominal lifetime.

Spacecraft routine operations still keep a team of eight spacecraft controllers and eight engineers extremely busy; the ground segment is however helping to carry out the daily tasks in time, and this is also shown by the fact that we could afford the time to write and present this paper.

The experience gained with the EURECA mission control should be used to improve for future missions the ground segment reliability and to reduce the involvement of man in all those tasks which can in principle be automated.